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Measuring Bremsstrahlung Photons in $\sqrt{s} = 200\text{GeV}$ p-p Collisions

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Direct photon production is an important observable in heavy ion collisions, as photons are penetrating and therefore largely insensitive to final state effects. Measurements of the fragmentation component of direct photon yields in p+p and Au+Au collisions will provide important tests of pQCD predictions and of predictions for modifications of this component in heavy ion collisions. By selecting photons associated with jets on the same side using hadron-photon correlations, fragmentation photons can be measured directly.

1. Introduction

The phenomenon of jet quenching is one of the key signatures for the presence of a hot dense medium in heavy ion collisions. The energy loss of jets as they propagate through the medium is thought to be largely due to medium induced gluon bremsstrahlung¹. However, because the radiated gluons interact with the medium, the radiation spectrum cannot be measured directly. There are several theoretical models that attempt to describe the mechanisms for jet energy loss, but all rely on a variety of assumptions including the thickness of the medium and the energy of the parton. It would be useful to have a direct probe of the radiating parton at all stages in its evolution. In addition to gluons, photons are produced through jet fragmentation, and therefore could provide just such a probe.

Direct photons provide a powerful probe of final state effects, because once produced they do not interact strongly with the medium. In p+p collisions, NLO perturbative QCD calculations for the single particle spectra agree well with the data, and the ratio of spectra for Au+Au collisions to that for p+p, scaled by the number of binary collisions, has already been used as a baseline for understanding final state effects on the suppression of high- p_T particles². At NLO, these pQCD calculations include a significant contribution from photons produced through par-

*For the full list of PHENIX authors and acknowledgements, see Appendix 'Collaborations' of this volume

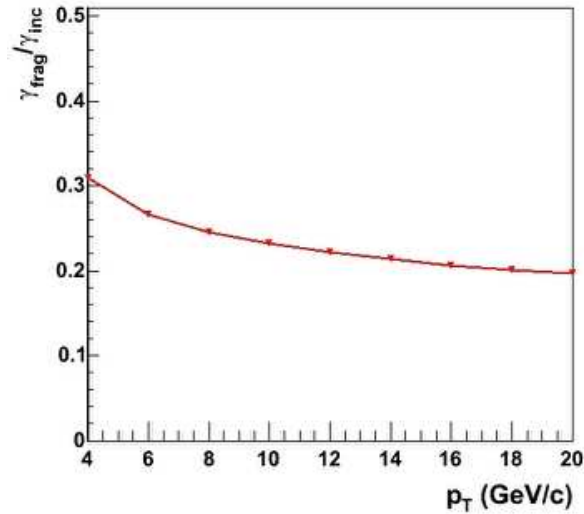
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Fig. 1. The ratio of fragmentation photon to inclusive direct photons using the INCNLO(v1.4) pQCD calculation³

ton fragmentation³. At low p_T ($p_T < 10.0$), the contribution is as much as 20-30% (Fig. 1).

In heavy ion collisions the fragmentation component to the inclusive direct photon spectrum can be modified. There are two main ways this contribution could be modified. If the partons begin radiating bremsstrahlung gluons prior to fragmentation, then the fragmentation photon spectrum would be suppressed by as much as 20-40% for $p_T > 3.0 \text{ GeV}/c$ ⁴. On the other hand, it is possible that additional photon bremsstrahlung would be induced through the interaction of the energetic parton and the medium, leading to an overall enhancement of the fragmentation photon spectrum for $p_T < 10.0 \text{ GeV}/c$ ⁵. This stimulated bremsstrahlung provides direct observation of the scattering of jets in the medium, and therefore a way to directly measure the radiation spectrum.

2. Method

It is possible to study modifications to the fragmentation component of the direct photon spectrum simply by looking at the R_{AA} and studying its deviation from unity⁶. However, because any modifications are likely to be a combination of stimulated bremsstrahlung radiation and suppression due to energy loss, and the fragmentation component is only a fraction of the total direct photon signal, it is difficult to extract much information this way. If instead, the fragmentation component could be measured directly, both in p+p and Au+Au collisions, it may be

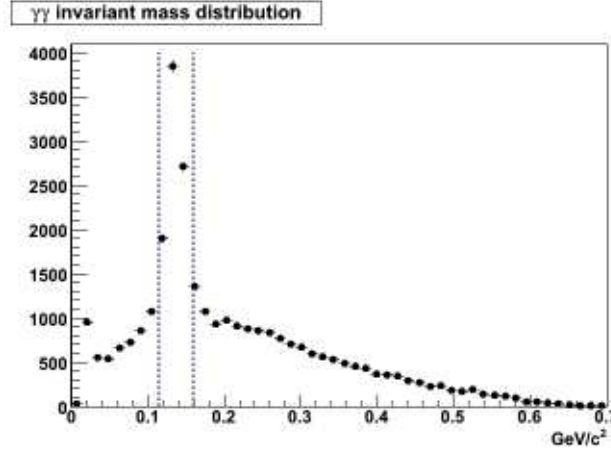


Fig. 2. Invariant mass distribution for photon pairs. The dashed blue lines indicate the mass cut for tagging photons coming from π^0 decays

possible to study modifications more closely. Because fragmentation photons will be strongly correlated with the high- p_T parton that produced them, one way of selecting directly for fragmentation photons is to look at hadron- photon correlations and look at the yield for associated photons on the near side. This reduces the background from other direct photons, which should have no correlation with the hadrons.

The first step is to obtain the inclusive hadron-gamma per trigger yield. This will include the contribution from fragmentation photons, but it will be dominated by decay photons.

$$\frac{1}{N_{trig}^h} \frac{dN^{h-\gamma_{inc}}}{d\Delta\phi} = \frac{1}{N_{trig}^h} \frac{dN^{h-\gamma_{frag}}}{d\Delta\phi} + \frac{1}{N_{trig}^h} \frac{dN^{h-\gamma_{dec}}}{d\Delta\phi} \quad (1)$$

The dominant source of hadronic decay photons is from π^0 decays. So the next step is calculate the invariant mass spectrum for photon pairs and tag those that fall within the π^0 mass peak (Fig 2). There is some inefficiency inherent in any tagging method, due to the finite acceptance of any detector, which must be accounted for to obtain the true π^0 decay yield. The tagging efficiency is defined as:

$$\varepsilon(\Delta\phi) = \frac{\frac{1}{N_{trig}^h} \frac{dN^{h-\gamma_{tag}}}{d\Delta\phi}}{\frac{1}{N_{trig}^h} \frac{dN^{h-\gamma_{\pi^0}}}{d\Delta\phi}} \quad (2)$$

To determine this efficiency, a fast Monte Carlo simulation is used to generate π^0 s, let them decay, and reconstruct them from the resulting photon pairs and study acceptance affects. The efficiency will be a function of both p_T and $\Delta\phi$. As the $\Delta\phi$ between the π^0 and the trigger hadron increases, the possibility that one

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of the decay photons falls outside the acceptance may increase. This will improve at higher p_T , when the initial π^0 is closer to the hadron in $\Delta\phi$. To correctly weight for both these effects, the input π^0 s are generated with a $\Delta\phi$ distribution around a dummy “trigger” hadron which is given a random ϕ and η within the detector acceptance. The $\Delta\phi$ distribution is determined from the data, as is the input p_T spectrum.

Once the generated π^0 has decayed, the resulting $\Delta\phi$ distribution between the trigger hadron and the decay photons can be calculated and broken up into bins in p_T of the associated photon. The resulting distribution for all photons that pass the acceptance cuts is then compared to distribution when both decay photons are required to pass the cuts. From these, the tagging efficiency can be calculated. In other words, the tagging efficiency is obtained by comparing the case when any single photon that has come from a π^0 decay is within the acceptance, and the case when both photons from the decay will be detected and correctly reconstructed. Figure 3 shows an illustration of this for γ p_T from $2.0 - 2.5 \text{ GeV}/c$.

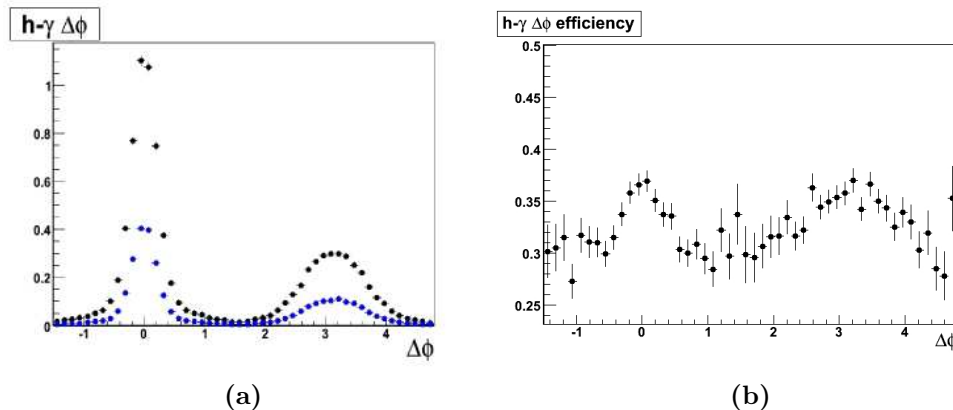


Fig. 3. **(a)** Simulated hadron- γ $\Delta\phi$ distributions for photons coming from π^0 decays, requiring one (black) or both (blue) of the decay photons to pass the acceptance cuts. **(b)** Efficiency for reconstructing π^0 associated with a high p_T hadron as a function of the $h - \pi^0$ $\Delta\phi$.

Once the efficiency is calculated, it can be folded back into the π^0 -tagged $h - \gamma$ yield to obtain the full $h - \gamma_{\pi^0}$ yield. However, while π^0 decays are the main source of background, other hadronic decays, for example $\eta \rightarrow \gamma\gamma$, are not negligible and must be included in the calculation of the full $h - \gamma_{dec}$ yield. Assuming that these additional decay contributions have similar $\Delta\phi$ distributions to the π^0 , the full decay yield is just the π^0 decay yield modulo the ratio of total $h \rightarrow \gamma$ decays to $\pi^0 \rightarrow \gamma$ decays, as shown in Eq. (3). Folding the tagging efficiency in, the total

decay yield can now be found in terms of the measurable tagged yield.

$$\frac{1}{N_{trig}^h} \frac{dN^{h-\gamma_{dec}}}{d\Delta\phi} = \underbrace{\frac{N_{h \rightarrow \gamma\gamma}}{N_{\pi^0 \rightarrow \gamma\gamma}}}_{R_{h/\pi^0}} \frac{1}{N_{trig}^h} \frac{dN^{h-\gamma_{\pi^0}}}{d\Delta\phi} = R_{h/\pi^0} \frac{1}{\varepsilon(\Delta\phi)} \frac{1}{N_{trig}^h} \frac{dN^{h-\gamma_{tag}}}{d\Delta\phi} \quad (3)$$

Plugging (3) back into (1) and solving for the fragmentation component gives an expression for the final $h - \gamma$ yield for fragmentation photons.

$$\frac{1}{N_{trig}^h} \frac{dN^{h-\gamma_{frag}}}{d\Delta\phi} = \frac{1}{N_{trig}^h} \frac{dN^{h-\gamma_{inc}}}{d\Delta\phi} - \frac{R_{h/\pi^0}}{\varepsilon(\Delta\phi)} \frac{1}{N_{trig}^h} \frac{dN^{h-\gamma_{tag}}}{d\Delta\phi} \quad (4)$$

3. Discussion

Perturbative QCD calculations match current data very well, and predict that fragmentation photons comprise a significant percentage of the total direct photon spectrum at low p_T . This fraction should be large enough to be directly measurable in experiment, once the background from decays has been accounted for. Many of the assumptions mentioned in this method still need to be studied, such as whether the $\Delta\phi$ distribution for non- π^0 hadronic decays is really the same shape as for the π^0 . For example, the η has a much larger opening angle, so it is possible that the shape of the yield will be modified. These differences may be very small, since η decays make up only a small fraction of the total decay contribution. However, because the fragmentation photon signal is already very small, even such small effects will need to be studied in detail.

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